

ELECTRONIC FUNDAMENTALS

THEORY LESSON 6

SECONDARY CELLS

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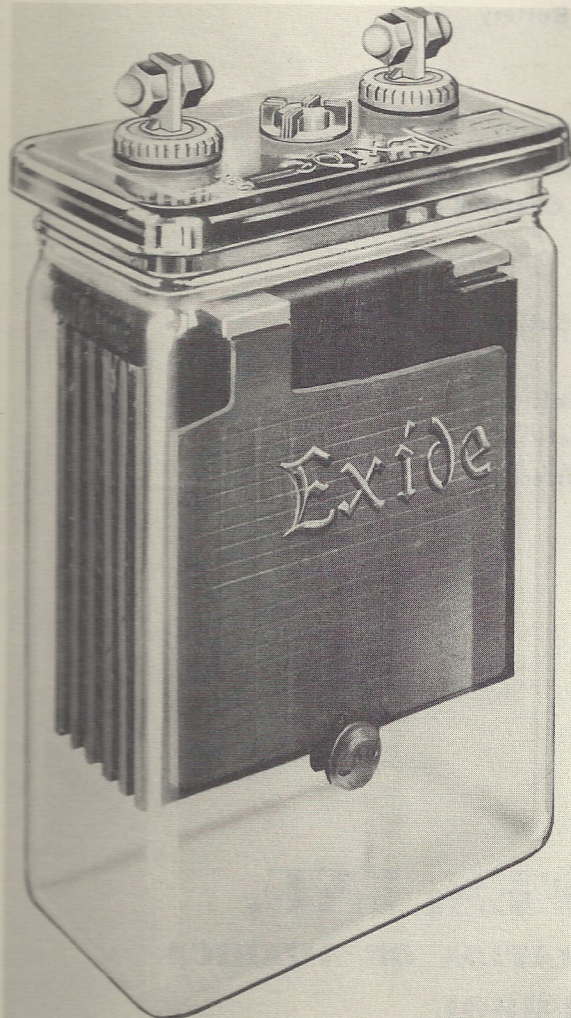
Theory Lesson 6

INTRODUCTION

In the last lesson, a *secondary cell* was partly defined as one that may be recharged when its electricity is used up. A more complete explanation follows: A secondary cell is a device that produces electricity by chemical action. When the emf produced by such a cell falls below a useful level, the chemical action can be reversed and the emf can be brought back to its original level. This is done by sending an electric

current through the cell in a direction opposite to the direction in which current flows as the cell is discharged. This action is called *charging*. When a cell receives its first charge, it is said to be *charged*. When it is charged again, we usually say it is *re-charged*. The same cell may be used over and over again, so long as it remains in good condition, is used properly, and is recharged when necessary. Secondary cells are often called *storage cells*, since they have the effect of storing electricity until needed. Like primary cells, storage cells may be connected together to form batteries. We call these batteries *storage batteries*. The most common form of storage batteries used in this country are the 6-volt and 12-volt automobile battery. Figure 6-1 shows a cell and a battery. A 6-volt battery contains three 2-volt cells; a 12-volt battery contains six 2-volt cells.

Like the primary cell, the storage cell is made up of two unlike substances and an



(a)



(b)

Fig. 6-1.

electrolyte. In this country, the commonest storage cell is the lead-acid cell. This cell is made up of two kinds of lead in a solution of sulphuric acid and water. It was stated in the last lesson that the electrodes of a cell must be of different substances. Yet, in a lead-acid cell, both electrodes are made from lead. The reason it is possible to produce a lead-acid cell is that the two kinds of lead have different characteristics and different potentials in the electrochemical series of metals. The positive electrode is made from lead peroxide, which is normally dark brown in color. The negative electrode is made from a gray, spongy lead. Both electrodes are highly porous (which means that they are full of pores or tiny holes). These small pores make it possible for the electrolyte to soak into the electrode and increase the capacity of the cell.

6-1. LEAD-ACID STORAGE BATTERY

A fully charged lead-acid cell produces an open-circuit voltage of about 2.2 volts. Under load, the voltage may drop to 2.0 volts or less. Some portable radios and other portable equipment are powered by such cells. In general, however, there is a need for a greater voltage, so cells are connected together in series to produce batteries.

Batteries of many sizes and many cells are made for all kinds of uses, but the 6-volt battery is familiar to most of us. Let us see how one is made. Figure 6-2 shows a cut-away view of a 6-volt storage battery, with each part identified. The parts that chemically produce electricity are the negative plates, the positive plates, and the electrolyte (which is not shown). Each plate of a modern lead-acid cell is built up by filling a metal *grid* or framework with lead peroxide (for the positive plates) or spongy lead (for the negative plates). Grids are made from an alloy of lead and antimony. The antimony adds strength to the lead, so that each grid may support the weight of the materials it is filled with. Figure 6-3a shows a grid partly filled with lead peroxide, and Fig. 6-3b shows a complete negative plate made from a grid filled with spongy lead.

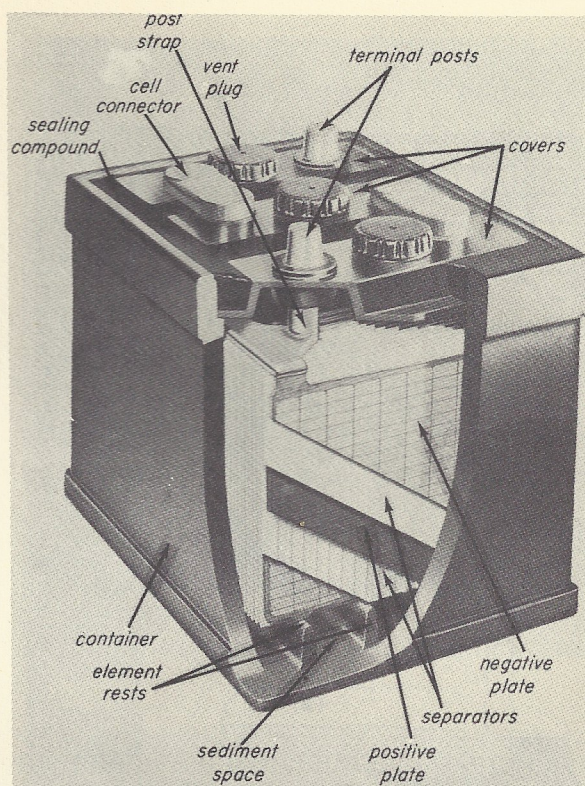
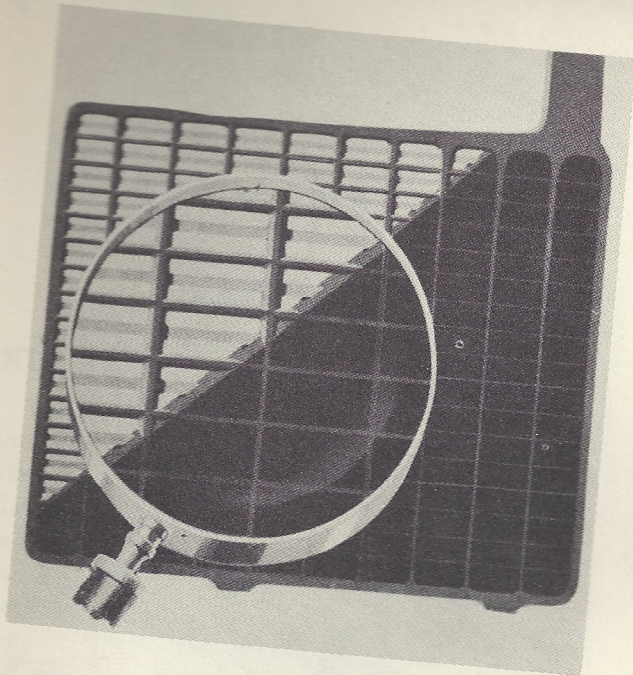


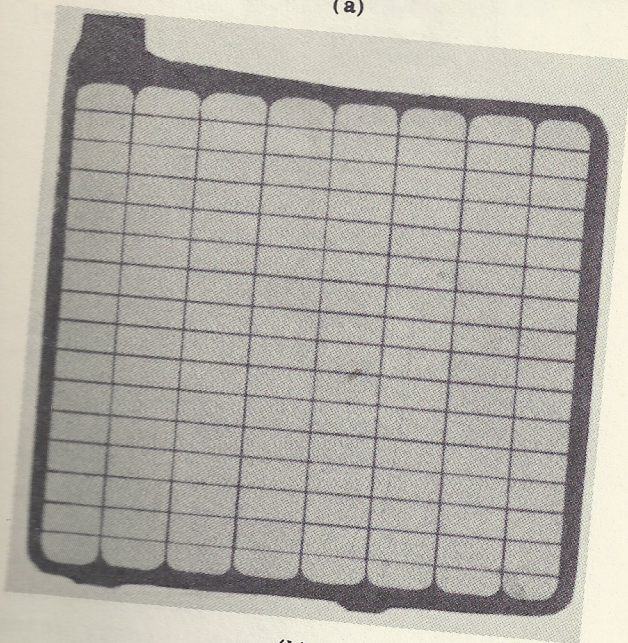
Fig. 6-2

To make cells of large capacity, several positive plates are welded together to form a positive element, and several negative plates are welded together to form a *negative element*. One of the ways in which storage batteries are rated is by the number of plates in each cell. Because the negative plates are on the outside of the positive plates, there is always one more negative plate than positive plate. Therefore, there is always an odd number of plates in a cell. For example, a thirteen-plate battery is made up of cells, each having six positive (lead peroxide) plates and seven negative (spongy lead) plates, while a twenty-one plate battery has ten positive plates and eleven negative plates in each cell. The plates of the positive and negative elements are interleaved, as shown in Fig. 6-4a.

Separators. To prevent a positive plate from touching a negative plate, a *separator* is slipped between each positive and negative plate. Separators are thin, non-conducting strips of porous wood, fiber, glass fiber, or rubber. No matter what they are made of,



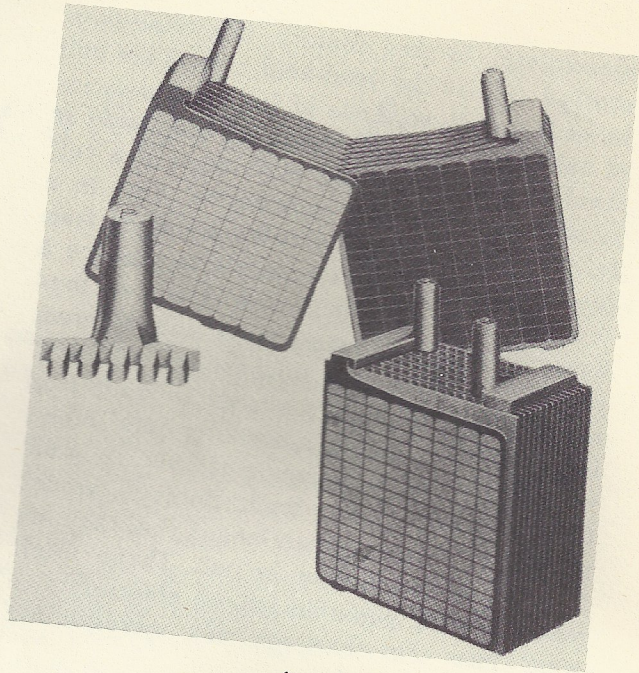
(a)



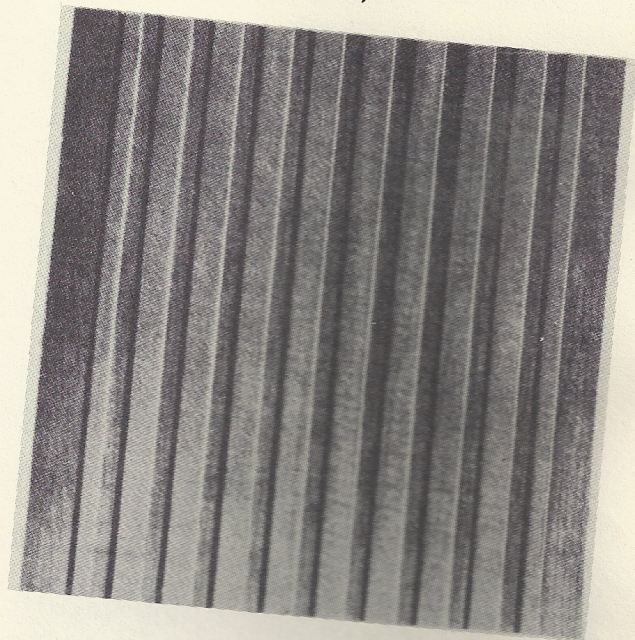
(b)

Fig. 6-3

separators must be non-conductors and porous enough to permit the passage of the electrolyte. Figure 6-4b shows a wood separator with grooves cut in one side. This side faces a positive plate. The function of the grooves is to permit a better flow of electrolyte within the cell.



(a)



(b)

Fig. 6-4

by a wall of the same material the case is made from. Molded rests or bridges for the cell element to rest on are at the bottom of each cell compartment. While discharging, or charging, or being subjected to a vibration, particles may flake or chip off the plates of a cell and settle at the bottom of the container. If the plates rested on the bottom of the case, the cell would be shorted. For this reason, the plates of the cell rest on the bridges, and room is left at the bottom to receive this loosened material. Each cell of a portable

Battery Container. The assembled cells are placed in a glass or hard-rubber container. As shown in Fig. 6-5, each cell compartment is separated from the next compartment

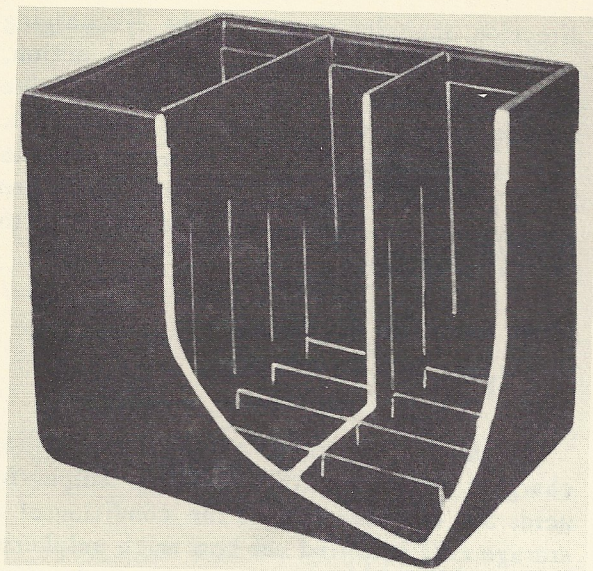


Fig. 6-5

battery, such as the kind used in automobiles, is covered with a hard rubber cover, as shown in Fig. 6-6. The hole at each end is slipped over the terminal post of a cell. The center hole is threaded to receive a cap, which may be removed for servicing the cell.

The cells are connected together by *cell connectors*, shown in Fig. 6-7a, which are made from lead or an alloy of lead and antimony. They must be heavy enough to carry a high current, such as that required of an automobile battery when starting the car. The negative and positive battery terminals are tapered, as shown in Fig. 6-7b, so as to receive any standard battery clamp. The positive terminal is always slightly larger than the negative terminal in order to prevent making battery connections in reverse. The individual cell covers are sealed to the battery case with a compound of a blown-oil asphalt or other tarry product. This sealing is necessary to prevent any accidental leakage of the acid solution. In this way, no

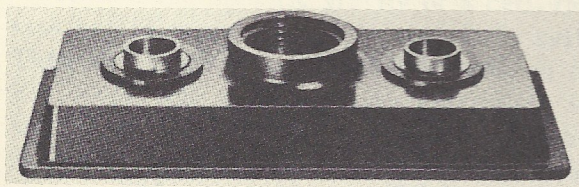


Fig. 6-6

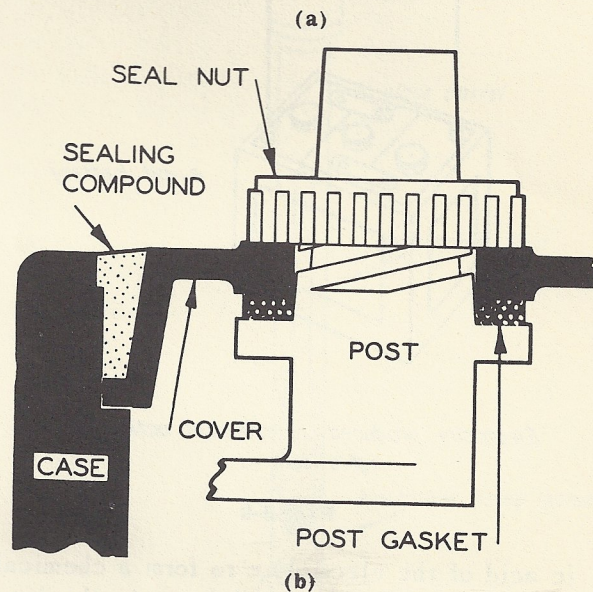
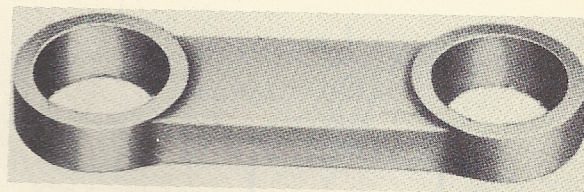
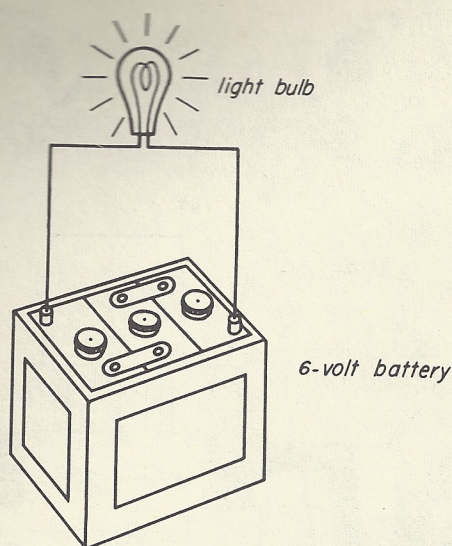


Fig. 6-7

acid is allowed to spill on and possibly destroy other surfaces.

Electrolyte. The electrolyte used in the lead-acid cell is a mixture of sulphuric acid and water. The electrolyte of a fully charged cell contains about 27%, by volume, of pure sulphuric acid. The other 73% is pure water. Most battery manufacturers suggest that only distilled water be used because, in many parts of the country, water contains chemical substances that may affect the chemical action of the cell or battery.

Chemical Action. The chemical action of the lead-acid cell is similar to the action of a primary cell. It is not important that we know all of the chemical changes that take place. It is sufficient if we understand that chemical action between the lead peroxide, the electrolyte, and the spongy lead can produce electricity, as shown in Fig. 6-8. However, we should know about some of the chemical changes that occur. As the cell is discharged in use, both the positive electrode (lead peroxide) and the negative electrode (spongy lead) combine with the sulphur-



Electricity produced by chemical action
lights bulb

Fig. 6-8

ic acid of the electrolyte to form a chemical substance called lead sulphate. In the language of battery men, the plates become sulphated. In producing this change, sulphuric acid is taken from the electrolyte. As a result, the electrolyte becomes weaker and weaker as the battery discharges. As more and more of the surface of each plate becomes sulphated, less and less electricity is produced. If the battery were to be completely discharged, the surface of each electrode would be entirely lead sulphate, and very little acid would remain in the electrolyte. For two reasons, therefore, no further electricity could be produced. First and most important, if two electrodes are made from the same substance, there is no potential difference between them. So, even if the electrolyte were full-strength, no emf could be produced. The second reason is that even if the electrodes were in their original condition, the electrolyte would be so weak that no effective emf could be produced.

In good practice, no battery or cell is ever permitted to become fully discharged. Either a cell is kept charged as it is used or it is recharged when the output voltage reaches a certain level. In recharging, an electric current is applied to the terminals of the cell and passes through the cell in a

direction opposite to that of the discharging current. This reverses the chemical action, and the sulphate is returned from the positive and negative electrodes to the electrolyte. This makes the positive plate once again lead peroxide, makes the negative plate spongy lead, and restores the electrolyte to its full strength.

6-2. SPECIFIC GRAVITY

We have seen that, as the battery discharges, the electrolyte loses sulphuric acid. So, one way to test the condition of a storage cell is to find out how much sulphuric acid remains in the electrolyte. At first glance, this might seem difficult to do, and it would be except for the fact that sulphuric acid is heavier than water. A pint of pure sulphuric acid weighs 1.835 times as much as a pint of water. We use water as a standard for measuring the relative weights of equal volumes of all kinds of substances. This relative weight we call *specific gravity*, and because water is used as the standard, we say that it has a specific gravity of 1. Because sulphuric acid weighs 1.835 times as much as water, it is said to have a specific gravity of 1.835.

Of course, the electrolyte used in lead-acid cells is not pure sulphuric acid, but a mixture of acid and water. By measuring, we find that the specific gravity of a fully charged lead-acid cell is about 1.280. Table A shows the approximate specific gravity of the electrolyte for different states of charge at a temperature of 80° F.

TABLE A - SPECIFIC GRAVITY
AND CHARGE AT 80° F

Specific Gravity	State of Charge
1.280	100%
1.250	75%
1.220	50%
1.190	25%
1.130	0%

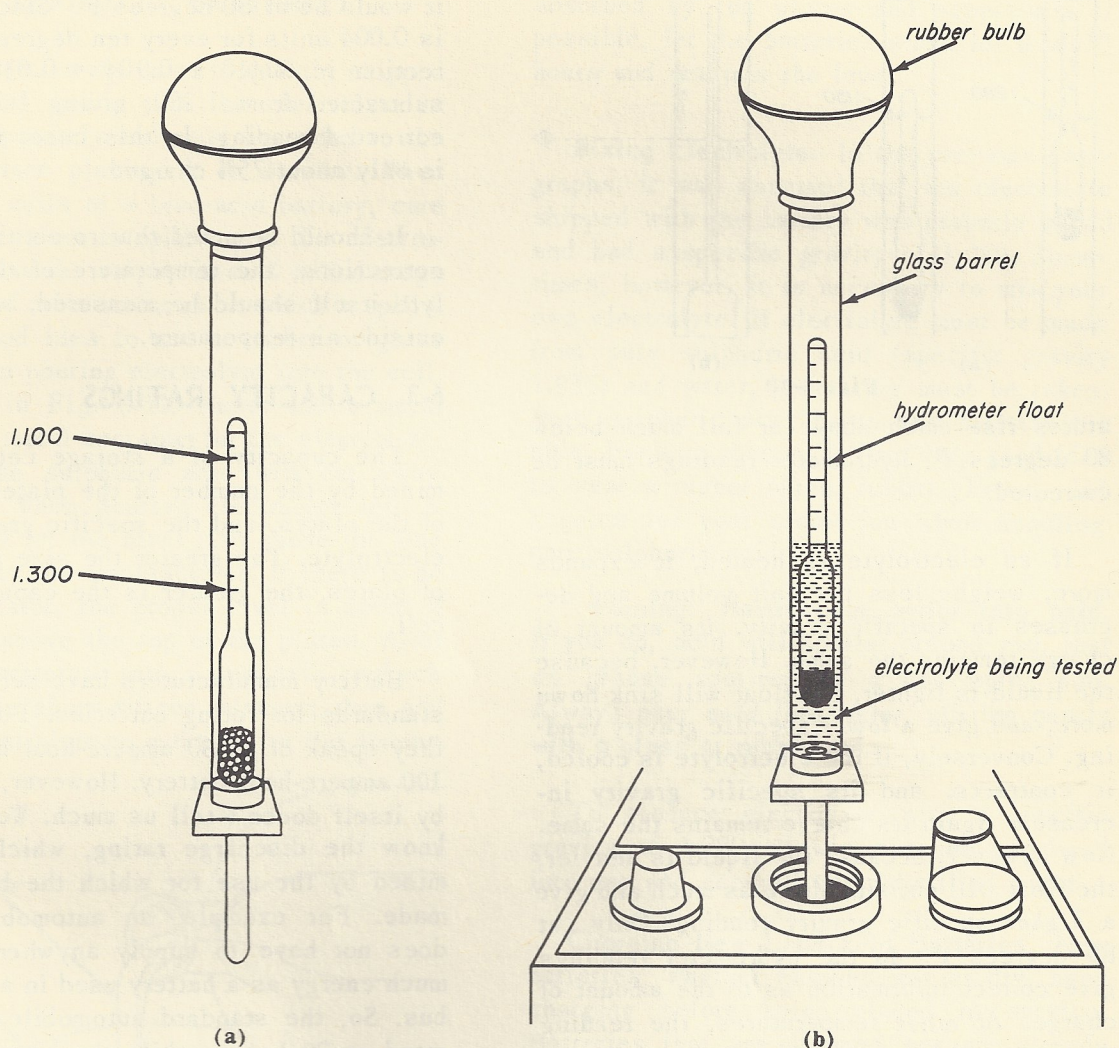


Fig. 6-9

Hydrometer. We measure the specific gravity of the electrolyte with a hydrometer. This instrument, shown in Fig. 6-9a, has a weighted float with a glass stem marked off like a thermometer. Instead of indicating temperature, however, it shows specific gravity. This float is enclosed in a glass tube with a flexible hose attached to the bottom and a rubber bulb at the top.

To test the specific gravity of a cell, the vent cap is removed from the top of the cell. Then the hydrometer is used, as shown in Fig. 6-9b, and enough of the electrolyte is sucked up into the hydrometer so that the float floats freely. To take a reading, your eye must be at the level of the fluid in the hydrometer. In this position, note the specific gravity as marked on the stem of the

float. Typical readings are shown in Fig. 6-10a and b.

Note that the lighter the liquid the more the float sinks down. When the liquid is heavier (higher specific gravity) the *less* the float sinks down. Thus the lower specific gravity numbers are nearer the top of the float.

After the reading is taken for one cell, the electrolyte is returned to the cell. In the case of a battery, test each cell, one at a time. Always be sure to return the electrolyte to the cell from which it was taken.

Temperature and Hydrometer Readings. Most hydrometers made for testing lead-acid cells are accurately marked for an electrolyte temperature of 80 degrees F. When temper-

6-4. NEW LEAD-ACID BATTERIES

New batteries are quite frequently shipped "dry". That means that the electrolyte is shipped separately and must be added to the battery before placing it in service. When filling the cells of a lead-acid battery, care must be taken not to spill any of the electrolyte, because the sulphuric acid will damage clothing and other surfaces on which it spills. It is a good idea to use a rubber or glass funnel when pouring electrolyte into the cell, as shown in Fig. 6-11. Never use a metal funnel or a metal container for the electrolyte, because the sulphuric acid will eat away the metal. When pouring electrolyte into a cell, do not let the level rise above the line indicated by the manufacturer. If there is no level indicator, the proper level is about $\frac{1}{4}$ to $\frac{1}{2}$ inch above the top of the plates. After pouring electrolyte into a new cell, recheck the level in about fifteen minutes; then add enough electrolyte to make up for the amount

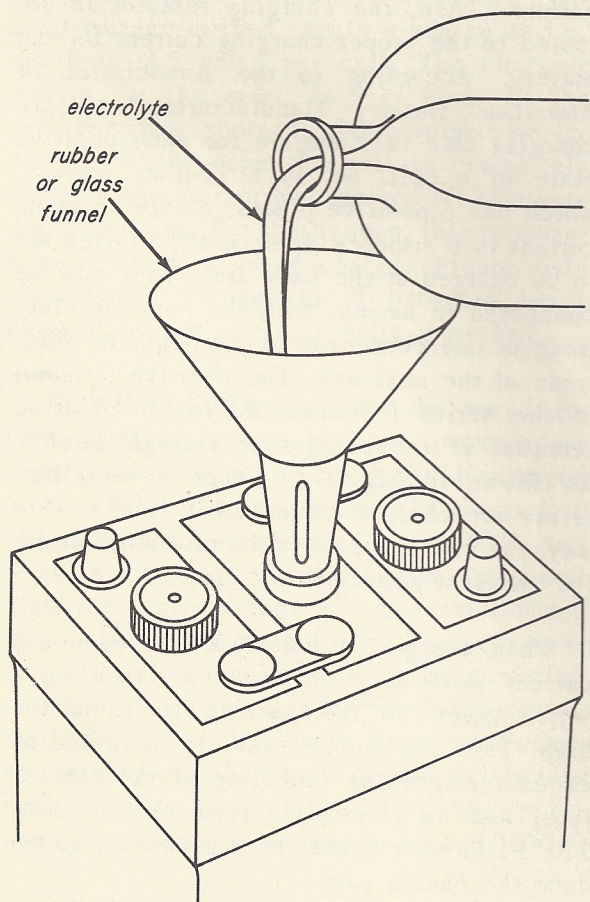


Fig. 6-11

absorbed by the plates and separators. If possible, let the batteries stand for 8 to 10 hours and readjust the level.

Mixing Electrolyte. In the previous paragraphs, it was assumed that the electrolyte shipped with the battery was properly mixed and had a specific gravity of 1.280. Sometimes, however, it is necessary to mix your own electrolyte. If electrolyte must be made from pure sulphuric acid (specific gravity 1.835) and water, great care must be taken. Pure sulphuric acid burns and blisters the skin. For that reason, it is a very good idea to wear a rubber apron, rubber gloves, and goggles for your protection when handling pure sulphuric acid.

Warning: Never pour water into acid. If you do, acid will spatter around you, just as grease spatters in a hot frying pan. Always pour acid into water, stirring gently with a glass or rubber rod.

To produce electrolyte with a specific gravity of 1.280, slowly mix one part acid into two and one-half parts distilled water.

Charging New Lead-Acid Batteries. New batteries, whether shipped wet or dry, need charging before being placed in service. Batteries that are shipped wet are already charged. However, a light finishing or "boosting" charge, at a low rate, is recommended. Batteries shipped dry must be fully charged before placing in service.

After charging a new battery, we may find that the electrolyte has a specific gravity greater than 1.280. In such cases, it is necessary to add sufficient distilled water to bring the specific gravity down to the proper level. It may be necessary to draw off some of the electrolyte to make room for water. However, any dilution of the electrolyte should be done slowly, with frequent testing, so that the electrolyte does not fall below the proper level.

6-5. BATTERIES IN SERVICE

Batteries in service should never be per-

mitted to become completely discharged. The specific gravity of the electrolyte should never be permitted to fall below 1.150. In addition, batteries should never be permitted to remain discharged for any length of time. Some battery manufacturers recommend recharging when the specific gravity reaches 1.175 or 1.200.

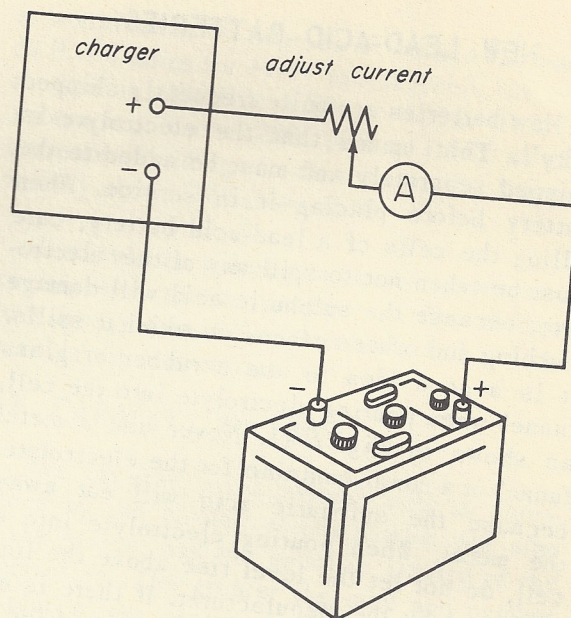
6-6. GENERAL RULES FOR CHARGING

Batteries should be charged in a well-ventilated room. While charging, lead-acid cells and batteries give off oxygen and hydrogen. So, no matches, lighted cigarettes or cigars, or sparks of any kind should be permitted near a charging battery. Keep vent caps screwed tightly on cells. This will prevent spattering of acid from the cells during charging. Before placing a battery on charge, clean all dirt and corrosion from the terminals. See that the vent hole in each vent cap is open and clear of dirt and grease. Make sure that the electrolyte of each cell is at the proper level. If not, add sufficient distilled water to bring it to the proper level. Battery manufacturers urge you not to add acid, any other type of electrolyte, or any battery "dope". Just add water to the proper level.

6-7. CHARGING METHODS

No matter which method of charging is used, batteries are charged by placing direct current of the proper voltage and polarity across the terminals of the battery. A battery is considered to be fully charged when all cells are bubbling freely and no change in voltage or hydrometer readings is observed during four successive hourly readings. There are several methods of charging in use. These are *constant-current* charging, *constant-voltage* charging, *high-rate* charging, and *trickle* charging.

Constant-Current Charging. The oldest and most used charging method is the constant-current method. As shown in Fig. 6-12, the positive terminal of the charger is connected to the positive terminal of the battery

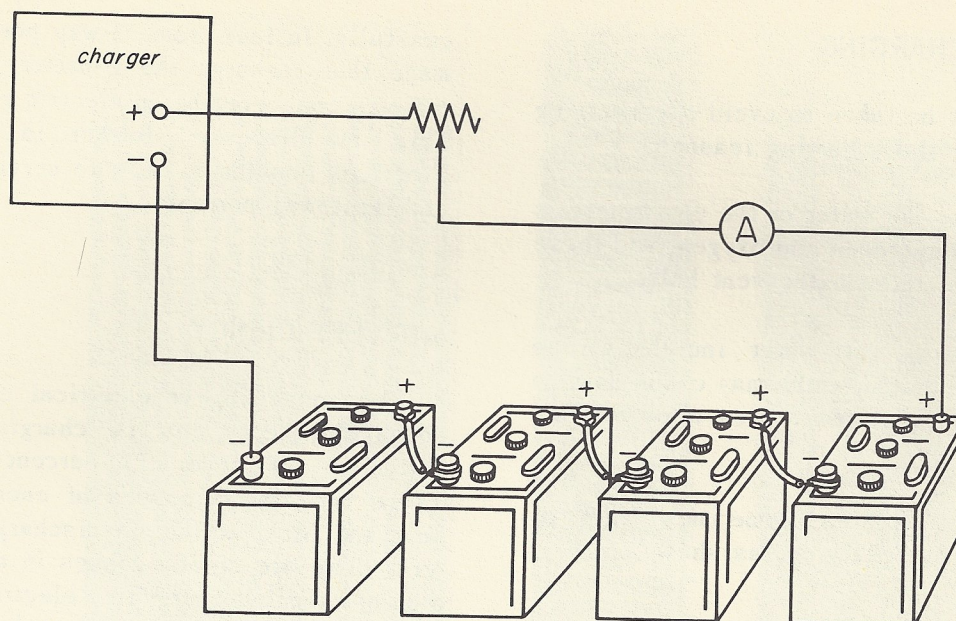


constant-current charging
Fig. 6-12

and the negative terminal of the charger is connected to the negative terminal of the battery. Then, the charging resistor is adjusted to the proper charging current for the battery. According to the Association of American Battery Manufacturers, a safe charging rate is 1 ampere for each positive plate in a cell. So, in a 13-plate battery, which has 6 positive plates, a safe charging current is 6 amperes. If several batteries are to be charged at the same time, they may be connected in series, with the positive electrode of one connected to the negative electrode of the next one. The positive terminal of the series is connected to the positive terminal of the charger or voltage source, as shown in Fig. 6-13. When several batteries are charged at the same time in this way, the charging rate is the rate suitable for the smallest battery in the line.

When charging a battery by the constant-current method, it is necessary to keep a watch to see that the charging rate is not too high. This condition is usually indicated by excessive gassing (bubbling of the electrolyte) and by electrolyte temperatures over 110°F. In such cases, it is necessary to reduce the charge rate.

Constant-Voltage Charging. When batteries are not badly sulphated or are not too



constant-current charging of batteries connected in series

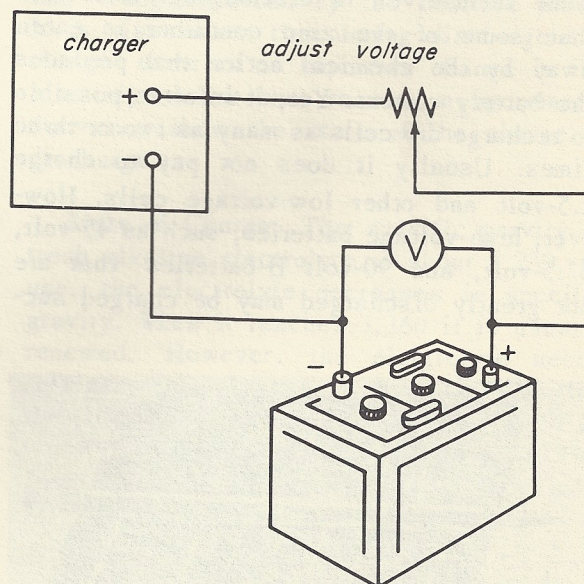
Fig. 6-13

greatly discharged, the time required for charging may be reduced by using the constant-voltage method. Apply a source of d.c. equal to 2.5 volts per cell. The charging current, at the start, is very high. As the cell becomes charged, the current rate reduces; by the time the cell is completely charged, the current has tapered off to a very small quantity. For that reason, this is sometimes called a *taper charge*. Figure 6-14 shows one arrangement of batteries being charged by the constant voltage method.

High-Rate Charging. Since the war, high-rate chargers have become increasingly popular. If a battery is not badly discharged or over-sulphated, as long as the electrolyte temperature does not rise above 125°F, and there is no excessive bubbling, an occasional high-rate charge does no material damage to a battery. Great care must be used, however, to follow the instructions for operating a high-rate charger. Otherwise this charge can cause great damage to batteries. Batteries shipped dry should not be charged by this method, since, in such batteries, the temperature should not be allowed to exceed 110°F.

Trickle Charging. Trickle charging is really a form of constant-voltage charging,

except that it is applied continuously with a low charging current. The charging current is usually 1% or 2% of the ampere-hour rating of the battery. The storage cells used in some makes of 3-way portable radios use a trickle-charging circuit to charge the cell whenever the radio is connected to an electric power line. A typical circuit of this type is shown in the Service Practices booklet on portable radios.



constant-voltage charging

Fig. 6-14

6-8. OVERCHARGING

Care must be taken to avoid overcharging a battery for the following reasons:

1. Some of the water of the electrolyte is changed into hydrogen and oxygen, and these gases escape through the vent hole.
2. The loss of water increases the strength of the acid, which may cause damage to the negative plates and to wood or fibre separators.
3. Positive plates sometimes warp or buckle from overcharging, as shown in Fig. 6-15.
4. High internal heat frequently results from overcharging. This increases the rate of corrosion and may soften the sealing compound used in assembling the battery.
5. Excessive amounts of sediment form at the bottom of each cell.

6-9. CHARGING PRIMARY BATTERIES

In the lesson on primary batteries, it was stated that such batteries tend to consume themselves in discharging. It is true that some of the zinc container is eaten away by the chemical action that produces the battery current. Yet, it is often possible to recharge dry cells as many as two or three times. Usually it does not pay to charge 1.5-volt and other low-voltage cells. However, high-voltage batteries, such as 45-volt, 67.5-volt, and 90-volt B-batteries that are not greatly discharged may be charged suc-

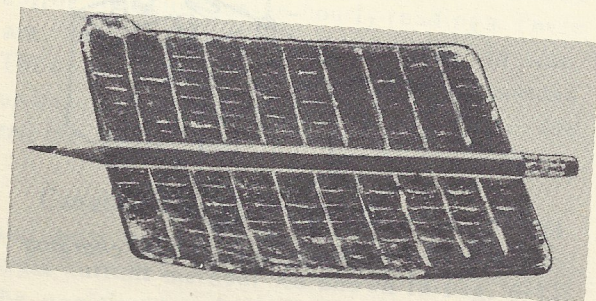


Fig. 6-15

cessfully. In fact, some 3-way portables are made that recharge the B-battery when the radio is connected to an electric power line. This is discussed further in a Service Practices booklet on how to service battery and three-way portables.

6-10. EFFICIENCY

The converting of electrical energy into chemical energy, as in charging storage batteries, is never 100-percent efficient. There are always losses of energy due to heat and local action. In discharging a battery, there are similar losses in the conversion of chemical energy into electrical energy and in overcoming the internal resistance of the battery. However, while there is some loss in efficiency, the portability and convenience of batteries make them indispensable for many types of equipment.

6-11. EDISON ALKALINE CELL

The Edison alkaline cell is a storage cell that has widespread use in telephone central offices, railway signalling, and communication on railroad trains and in battery-operated trucks. Although Edison cells originally cost more than lead-acid cells, their long life and lighter weight frequently make them more economical to use over long periods of time.

Positive Plates. The positive plates of an Edison cell, as shown in Fig. 6-16a, are made from nickel-plated steel tubes filled with 315 layers of nickel flakes, with a layer of nickel hydroxide between each layer of flake nickel. These tubes are normally $1/4$ or $3/16$ of an inch in diameter and usually 4.5 inches in length. The tubes are punched with many small holes and reinforced with eight nickel-plated rings. They are then mounted on a nickel-plated steel grid, as shown in Fig. 6-16b.

Negative Plates. The negative plates are made from rectangular nickel-plated steel containers known as *pockets*. Each of these is punched with many fine holes and

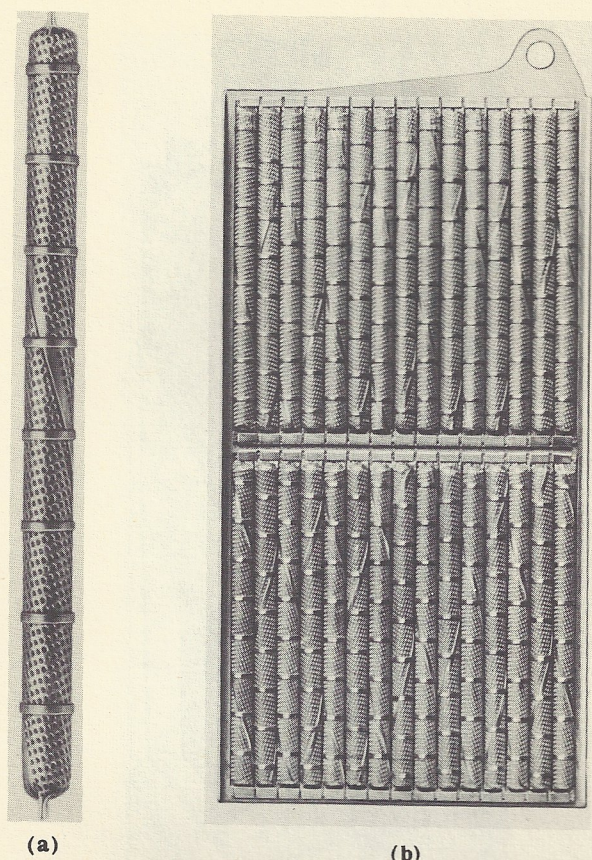


Fig. 6-16

filled with ferrous oxide (iron oxide) mixed with a little yellow oxide of mercury. The negative pockets are mounted on a nickel-plated steel grid to form the negative plate. Figure 6-17 shows a single negative pocket and an assembled negative plate.

The Electrolyte. The electrolyte is potassium hydroxide, and a small amount of lithium hydroxide, in water. The cells have nickel-plated steel terminal posts, specially tapered to fit the connectors made to join one cell to another. The cells are mounted in a case made from nickel-plated sheet steel. As shown in Fig. 6-18, the positive plates are mounted on a steel rod, evenly spaced by washers between each plate. The negative plates are assembled in the same way. Then the negative plates and the positive plates are interleaved, as shown in Fig. 6-18.

Chemical Action. Studies have been made of the chemical action that takes place in a charging and discharging nickel-iron storage cell (another name for Edison cell). However, exactly what happens is not yet

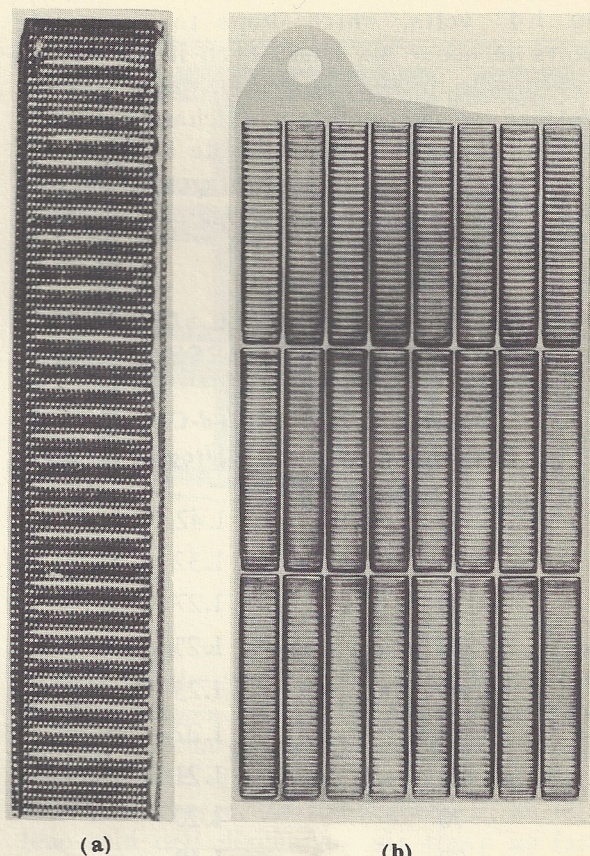


Fig. 6-17

completely understood. It is known that in discharging, oxygen is liberated by the positive plate and added to the negative plate. In charging, the action is reversed, with the oxygen leaving the negative plate and being absorbed by the positive plate. It is also known that during discharge and charge there is no important change in the electrolyte. For that reason, a hydrometer does not show the state of the charge or discharge.

State of Charge. The specific gravity of fresh alkaline electrolyte is about 1.230. In use, the electrolyte decreases in specific gravity. When it reaches 1.160 it is usually renewed. However, the electrolyte needs this renewal only two or three times during the life of the battery. The electrolyte is renewed by replacing the old electrolyte with fresh renewal electrolyte made especially for this purpose.

To determine the state of charge, it is necessary to measure the closed-circuit voltage of the cell under normal load. Freshly charged, the output of an average Edison cell

is 1.47 volts, which drops to about 1.42 volts in about six hours even if the cell is not used in the meantime. The terminal voltage of a completely discharged Edison cell is about 1.13 volts. Table B shows approximate closed-circuit voltage readings of an Edison cell in discharging.

TABLE B - EDISON CELL VOLTAGES DURING DISCHARGE

Percent Discharge	Closed-Circuit Voltage
0	1.42
10	1.32
20	1.27
30	1.25
40	1.23
50	1.22
60	1.21
70	1.20
80	1.19
90	1.17
100	1.13

Charging Edison Cells. For best results, the temperature of the electrolyte before charging should be between 70° and 80°F. If charged while the electrolyte is at a higher temperature, the capacity of the cell may be reduced during the next discharge period. Because the temperature of Edison cells rises considerably during discharging, as well as during charging, it may be necessary to let the cell cool off before charging. Edison cells are best charged by the constant-voltage method. The manufacturer's directions must be followed carefully when charging.

6-12. NICKEL-CADMIUM CELL

The nickel-cadmium cell is very much like the nickel-iron cell, except that the negative electrode is usually cadmium or a mixture of cadmium and iron. Figure 6-19 shows a cut-away view of a nickel-cadmium

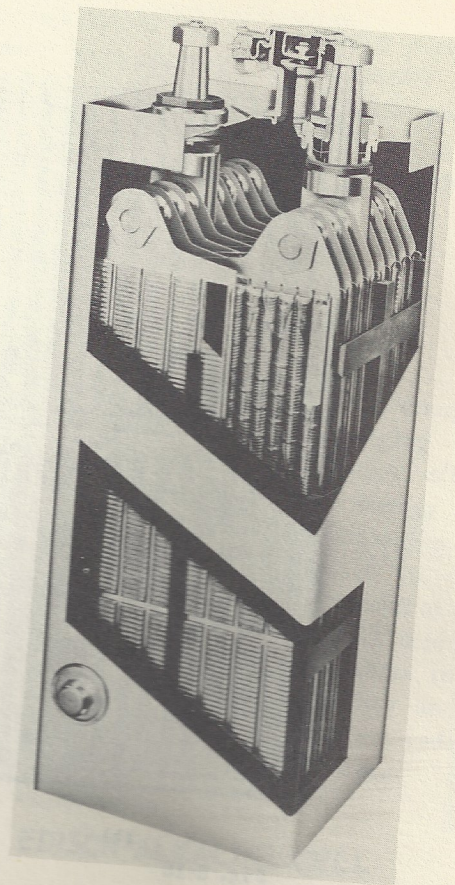


Fig. 6-18

cell. The electrolyte used is potassium hydroxide with a normal specific gravity of 1.210.

The open-circuit voltage of a nickel-cadmium cell is about 1.3 volts. When loaded so that it discharges at the normal rate suggested by the manufacturer, the closed circuit voltage is approximately 1.2 volts, until it is about 75-percent discharged. Some nickel-cadmium cells are considered discharged when the closed-circuit voltage reaches 1.1 volts and, in other cells, when the voltage reaches 1.0 volts. For charging rates, follow the manufacturer's instructions.

Nickel-cadmium batteries are much more common in Europe, where they have been manufactured and used for many years. They are used for train lighting, mine lamps, in trucks and tractors, for communication systems, and to start marine engines. They have long life, are very rugged in construction, and require little attention.

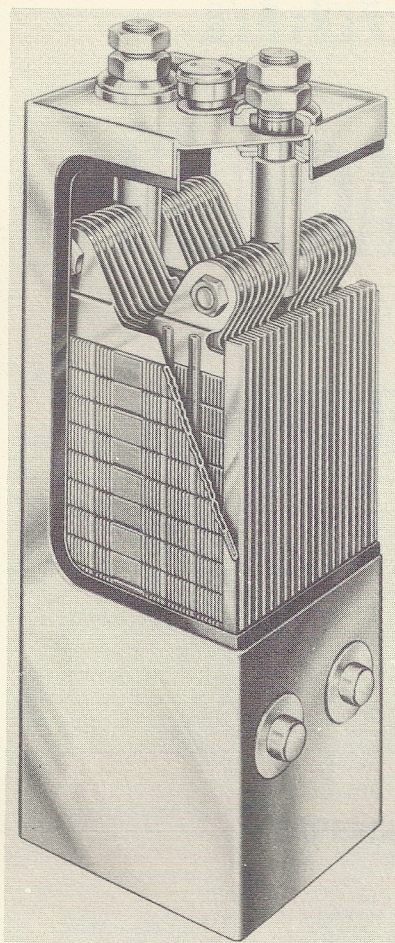


Fig. 6-19

6-13. STORING STORAGE BATTERIES

New lead-acid batteries that have been shipped dry may be stored for an indefinite period of time so long as the vent caps remain sealed and are not removed. Batteries that are received fully charged and ready for service should be stored in a cool place

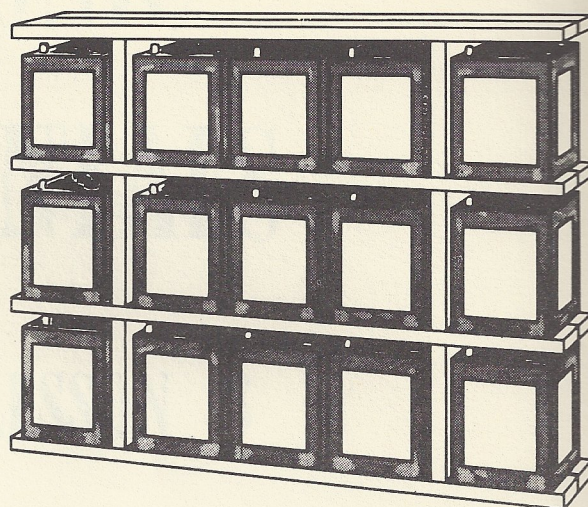


Fig. 6-20

with plenty of ventilation. They may be placed on shelves, as shown in Fig. 6-20. Sufficient room should be allowed for connecting a charger to the terminals. While standing idle in storage, lead-acid batteries slowly discharge. At 100-degrees F, an idle lead-acid cell discharges six times as fast as it does at 50-degrees F. So, every so often lead-acid batteries need a booster charge to bring the specific gravity of the electrolyte up to a normal figure.

Batteries that have been in use should be recharged before being stored, and should be inspected about every two weeks. Never store a discharged battery.

Nickel-iron and nickel-cadmium batteries should be stored in a well-ventilated, cool place. However, the amount of self-discharge is so small that they require very little attention.

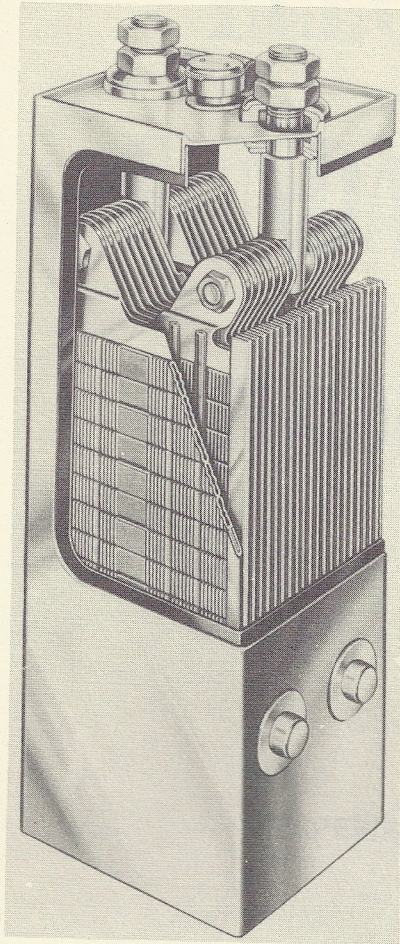


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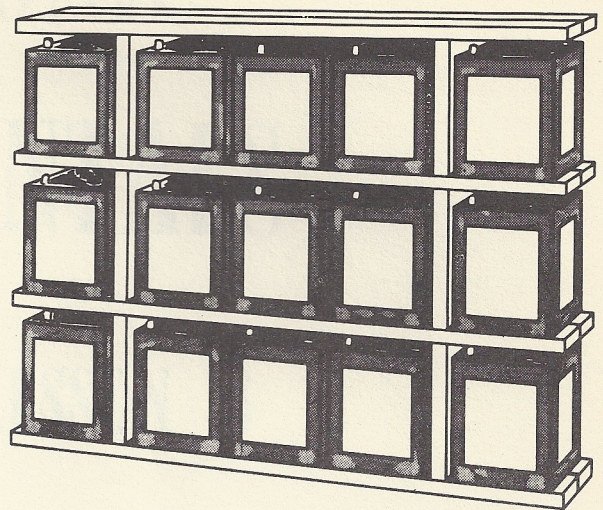


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